U.S. Mobile Offshore Base Technological Report

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ABSTRACT

The Office of Naval Research (ONR) is conducting a Science and Technology (S&T) Program to investigate the technical feasibility and cost of a Mobile Offshore Base (MOB). The concept of a MOB reflects the United States' need to stage and support military and humanitarian operations anywhere in the world. A MOB is a self-propelled, modular, floating platform that can be assembled into lengths up to 2 kilometers, as required, to provide logistic support of U.S. military operations where fixed bases are not available or adequate. A MOB would house personnel, accept cargo from rotary and fixed wing aircraft and container ships, maintain equipment, and discharge resources to the shore via a variety of surface vessels and aircraft.

At the inception of this Program, there were no standards, experience, or tools adequate for the design of multiply-connected MOB platforms. Those deficiencies served as the basis for defining the scope and breadth of this ONR science & technology program to assess this truly innovative structure.

This paper describes the many advances achieved during the approximately 3 year long ONR MOB investigation., It also summarizes the few remaining issues in need of resolution, and provides an opinion on MOB feasibility and cost.

INTRODUCTION

A Mobile Offshore Base (MOB) is intended to provide forward presence anywhere in the world. It serves as the equivalent of land-based assets, but is situated closer to the area of conflict and capable of being relocated. In operation, it would be stationed far enough out to sea to be easily defended.

As presently envisioned, a MOB is a self-propelled, floating, prepositioned base that would accept cargo from aircraft and container ships and discharge resources to the shore via a variety of surface vessels and aircraft (Remmers and Taylor, 1998). The basic strategy is to deploy semisubmersible "building block" modules which could be deployed in a number of different modes of operation. A typical module is shown in Figure 1. Each module consists of a box-type deck supported by multiple columns on two parallel pontoons. When transiting between operational sites, the module is deballasted and travels with the pontoons on the surface much like a catamaran. When on site, the module is ballasted down so that the pontoons are submerged below the surface wave zone, thereby minimizing the wave-induced dynamic motions. The decks, which store rolling stock and dry cargo, are all located above the wave crests. The columns provide structural support and hydrostatic stability against overturning.

A MOB platform could range anywhere in length from a single, 300 meter-long, module to multiple modules serially aligned to form a runway up to 2 kilometers long. All platforms would provide personnel housing, equipment maintenance functions, vessel and lighterage cargo transfer, and logistic support for rotary wing and short take-off aircraft. As illustrated in Figure 2, the longest platform (nominally 2 kilometers in length) would also accommodate conventional take-off and landing (CTOL) aircraft, including the Boeing C-17 cargo transporter (Polky et al., 1999).

Upon first inspection, the notion of a 2-kilometer long floating platform seems so far beyond the state-of-practice that it would not be worthy of serious discussion. There are, however, a variety of conceptual approaches that offer promise towards accomplishing that goal. This program chose to sponsor preliminary development of four candidate concepts, with the goal of providing future designers with a range of potential solutions that can be optimized to fit different mission requirements, constraints, and risks.

The U.S. Department of Defense has not yet formally addressed the operational requirements for MOB platforms. Therefore, this Science and Technology (S&T) Program adopted a strategy aimed at identifying

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and delivering a comprehensive suite of design guides and tools applicable to the widest possible range of platform configurations and sizes. The intended audience for these tools includes military planners, designers/ fabricators, classifiers, and users.

The next two sections of this paper present an overview of the platform designs and fundamental technology advances completed under this S&T Program. The final two sections discuss MOB feasibility and unfinished S&T tasks.

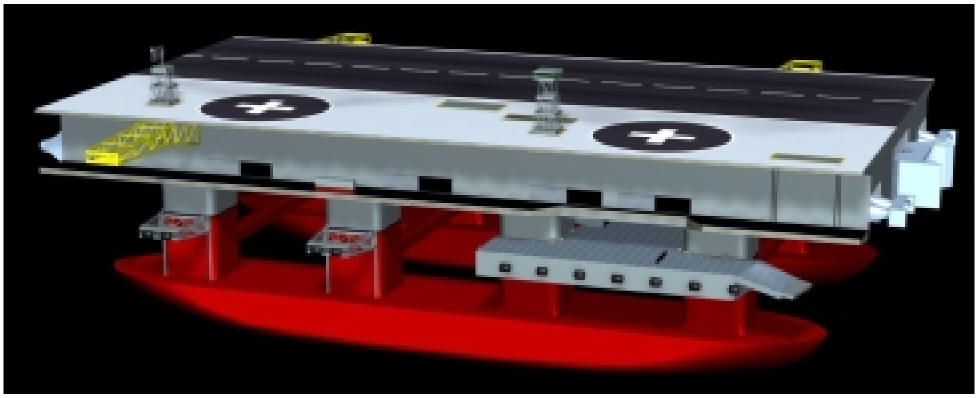

Figure 1. Representative MOB module (from J.R. McDermott Inc.)

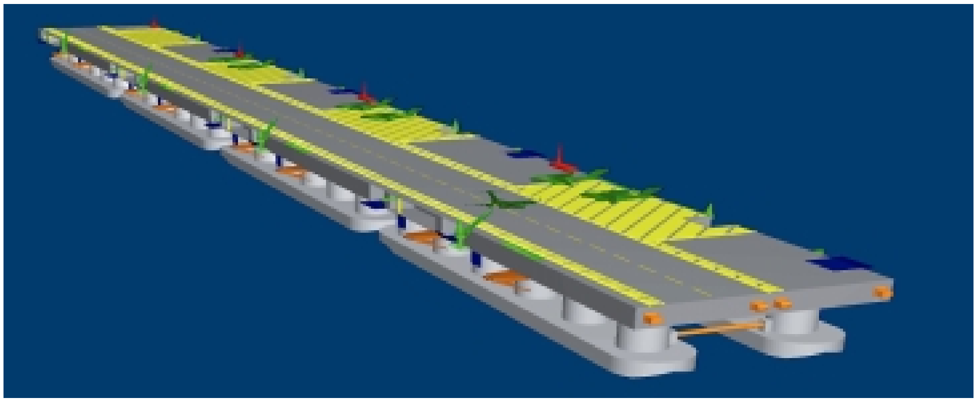

Figure 2. Representative CTOL-capable MOB platform (from Aker Maritime)

MOB PLATFORM DESIGN STUDIES

This program sponsored preliminary development of four candidate concepts for the following reasons: (1) to identify advantages and limitations of promising conceptual approaches for future designers, (2) to uncover technology problems requiring additional S&T, and (3) to support realistic cost estimating. As described in Remmers, et al., 1999, three of the four candidate concepts were chosen based primarily on their connectivity scheme:

- *Compliant*: Five identical 305m (1000ft) steel semisubmersibles connected using centerline ball joints and flexible edge connectors that allow the modules to pitch relative to one another (McDermott International; see Figure 1)
- *Flexible bridges*: Three 220m (725ft) steel semisubmersibles connected by two 430m (1410ft) flexible bridges with dampers that act as distributed connectors to maintain a continuous flight deck (Kvaerner Maritime)
- *Independent modules*: Three identical 500m (1650ft) steel semisubmersibles that rely principally on dynamic positioning to maintain relative close position between modules
- *Hybrid:* Four identical 380m (1250ft) semisubmersibles with steel decks and concrete columns and pontoons that use an elastomeric bearings (Aker Maritime; see Figure 2) The fourth

concept explored the advantages of reinforced concrete for the lower hull:

The goal for all of these system studies was to maximize their advantages, as well as to understand and minimize any inherent non-optimal characteristics. Based on progress to-date, the program's present conclusion is that each approach can be made to satisfy nominal MOB mission requirements. Accordingly, each is a viable candidate for future MOB use, subject to specifics of the as-yet-undefined mission requirements.

These complimentary approaches will allow designers to optimize their platform designs by starting with a basic conceptual platform whose features are best suited to the mission priorities. Note that because of the uncertainty of the mission and, hence, platform requirements, as well as acquisition and/or life cycle costs, it is not appropriate for this S&T program to recommend or advance any particular approach as "optimum" at this time.

MOB S&T DRIVERS

The core objective of this Program is to establish MOB technical feasibility and cost. This objective was recast at the inception of this S&T Program into the question *"Do all tools necessary for designing and evaluating a MOB platform exist?"* It was concluded that a significant portion of the state-of-practice was not adequate to allow for the confident design of these unprecedented MOB platforms consisting of serially aligned modules. This determination set the theme of this S&T Program – to advance general offshore technology to a consistent and sufficient level for future MOB designers and planners, complimented by the four systems designs. But those advancements take time, which means that addressing the objective has been an eVol.utionary process, with confidence in those answers that increases as the knowledge base grows with each new S&T advancement. .

Therefore, the thrust of this S&T Program is focused on identifying, prioritizing, and advancing the key technologies, with the goal of delivering a comprehensive suite of design guides and tools applicable to the widest possible range of platform configurations and missions. One way to evaluate the completeness of this Program is through an assessment of the "S&T drivers identified at the Program inception" that were key to MOB technical feasibility. These drivers are listed below:

- Requirements and Design Criteria – necessary to define and trade-off mission requirements
- Design Capability – all computer models and design guidance necessary to build safe platforms
- Survivability – assessment of the consequences of external threats
- Functionality – ability to assess on-site mission performance
- Constructability – assessment of infrastructure capabilities to build MOB platforms
- Cost – provide approximate costs for four representative platform designs, and deliver generally applicable construction and life cycle cost estimation models

The following major S&T efforts sponsored under this ONR Program are briefly described as they relate to these six drivers.

Requirements and Design Criteria

The only previously existing document defining MOB requirements was a 1995 draft version of the "Mission Needs Statement (MNS)" that was never formally approved. Because a MNS is intended to serve as broad statements of general mission needs, the document is subject to wide differences in interpretation during the development of engineering design criteria. Although each concept developer used this MNS as the basis for establishing the engineering design requirements, the various assumptions used in those derivations resulted in different design criteria for each concept. Consequently, an objective comparison of the various concepts is not possible, nor was it the intent of the program.

To assess MOB feasibility and cost, it is necessary to understand the physical and economic impact inherent in each individual or combination of notional mission requirements. How large must a MOB be and what capabilities and performance characteristics are necessary to satisfy any of the proposed missions? To answer these questions and to provide future designers and planners with the tools necessary to a MOB design, procedures were developed for extracting uniform physical design criteria (such as runway length, deployment speed, cargo capacity and general configuration) from an assumed set of missions. These procedures were augmented as necessary with specific studies to more finely evaluate air operations, transit speed and container cargo transfer support. This process and the associated data base development established a traceable baseline set of requirements for the MOB and provides a rational procedure for modifying the baseline functional requirements to handle inevitable evolutions in the mission over time.

Design Capability

While it is certainly important that MOB modules be designed to satisfy the mission requirements, it is absolutely critical that they do not fail at sea under any circumstance by losing structural integrity or hydrodynamic stability. It is therefore critical for designers to have adequate computer analysis tools and design procedures to insure module safety. But because of its unprecedented size and multiple module configurations, it is not advisable to simply extrapolate existing offshore design practice to MOB platforms. Accordingly, this S&T program has sponsored a large number of studies directed at advancing offshore design capabilities to a level sufficient for MOB design with an acceptable and quantifable level of risk. This section summarizes work in two technical areas: (1) development of a comprehensive design guide, and (2) advancement of hydrodynamic and hydroelastic computer models suitable for MOB modules and platforms.

Design Guide: A preliminary *MOB Classification Guide* was developed in conjunction with the American Bureau of Shipping (ABS) and a team of academic, government, and industry experts (ABS, 2000). This *Guide* provides a reliability- and performance-based design process addressing structural integrity and hydrodynamic safety of the MOB modules and connected platforms. Essentially, its sole purpose is to insure that MOB modules have acceptable fatigue lives and can safely survive storms. It is primarily a commercial standard, augmented where appropriate by Department of Defense requirements.

The *Guide* is an integrator for all the technologies relevant to MOB design. It was developed with full recognition that it must encompass all relevant design tasks and the uncertainty in the results would be dependent on the uncertainty of all of the component models, coefficients, and excitations. Without historical precedents, the exceptional size and nature of MOB modules and platforms meant that this first release would require further refinement before it could be considered mature enough for offshore use. A parallel and independent assessment of the *Guide* was also considered essential to uncover omissions and/or topics that required additional study.

Supporting studies included development of: (1) a fracture-mechanics-based fatigue model suitable for large, one-of-a-kind connectors; (2) first application of a reliability-based fatigue assessment technique to surface ships; (3) survey of the state-of-practice for large marine connectors (mainly Tension Leg Platforms and Floating Production, Storage, and Offloading systems); (4) advancement of vessel stability evaluation from hydrostatic to hydrodynamic (including transit draft); and (5) environmental compliance assessment.

Computer Models: This S&T Program is also coordinating the development, advancement, and partial validation of several hydrodynamic and hydroelastic computer models to compliment the *Guide*. Most available hydrodynamic analysis tools model the semisubmersible hull as rigid and the waves as small; the [relative] simplicity of this [frequency domain, diffraction theory] approach serves as the industry state-of-practice because it provides reasonably accurate predictions of dynamics in waves on a small scale. Their use for MOB is very computationally intensive, however, in that they must account for the relative interactions among multiply-connected modules, or a MOB/vessel system.[3] This Program sponsored development of two new hydrodynamic models preliminary for fatigue and air gap design purposes, as well as a comparative assessment of all existing hydrodynamic models for MOB use. Next, one time domain model was advanced that does account for the actual instantaneous position of the hull and waves; this model is best suited for the dynamic analysis of single module motions in extreme seas. Two sets of 1:70 scale laboratory hydrodynamic validation experiments (see Figure 3) have been completed for transit dynamics and wave field/air gap.

However, the most pioneering advancements in this S&T topic are centered on hydroelastics, where "hydroelastic" refers to models which allow for hull structural deflections in the waves. The cornerstone of these advancements is the advancement of the HIPAN higher-order diffraction theory model by incorporating hydroelasticity, and adding a fast equation solver that decreased the computational times by up to three orders of magnitude. A universal hydroelastics-to-structural pressure translation model was also developed that maximizes the accuracy of finite element structural analyses by interfacing that modeling with hydroelastic pressure loads. Lastly, a comprehensive set of hydroelastic validation experiments was sponsored to

[3] **Note:** While the semisubmersible hull form is more stable in waves than a displacement hull, each column and pontoon does diffract and radiate waves such that the wave field surrounding the MOB is typically quite complex.

allow evaluation of these new models. These laboratory tests, completed in February 2000, measured the dynamic responses and internal strains of 1, 2- and 4-module connected semisubmersible physical models each 6 meters long (Smith, et al., 1999).

Survivability

There are two distinct topics in this S&T driver. The first is survivability to natural phenomena such as typhoons and hurricanes. The second is survivability to explosive threats.

Within the first topic of natural phenomena, there are two categories of studies that were motivated by the recognition that the available information regarding winds, waves, and currents ("metocean" conditions) at 2-kilometer scales was inadequate for MOB design. This was important for two reasons. First, and most importantly, all structural studies had conclusively shown that the forces in MOB connectors were maximum for near-beam-on waves that induced a torquing response. Second, spatial variations over this scale, or even the nominal 300-500m length of individual modules, affected the operation of the dynamic positioning thruster system. The first S&T study in this topic developed a preliminary metocean assessment which included a comprehensive report and two complimentary databases of hindcast metocean data. The first database contains metocean statistics at 6 hour intervals at 22 representative sites for 23 years, and the second at a refined scale specifically for 25 major typhoons; (see Pawsey and Manetas, 1999). In essence, this assessment collected and evaluated all available information on winds, waves, currents, internal waves, solitons, and storm fronts, and used that information to identify phenomena where further S&T was needed. This information was intended for fatigue and survival (typhoons/ hurricanes) structural design use as well as dynamic positioning.

The second natural phenomena survivability category that this S&T Program is sponsoring is a coordinated set of pioneering studies specifically addressing the topic of wave crest lengths, or equivalently, spatial coherence. The justification for these studies is the recognition that crest lengths directly affect the connector loads (particularly for the torque case), and hence the structural design procedures in the *MOB Classification Guide* would be incomplete without such information. These ongoing wave studies include: the first complete measurements of surface waves in several hurricanes, analysis of waves measured from satellites and the Space Shuttle, and analysis of data from a wave array of fixed staffs. One early surprise from these studies is the direct confirmation that the

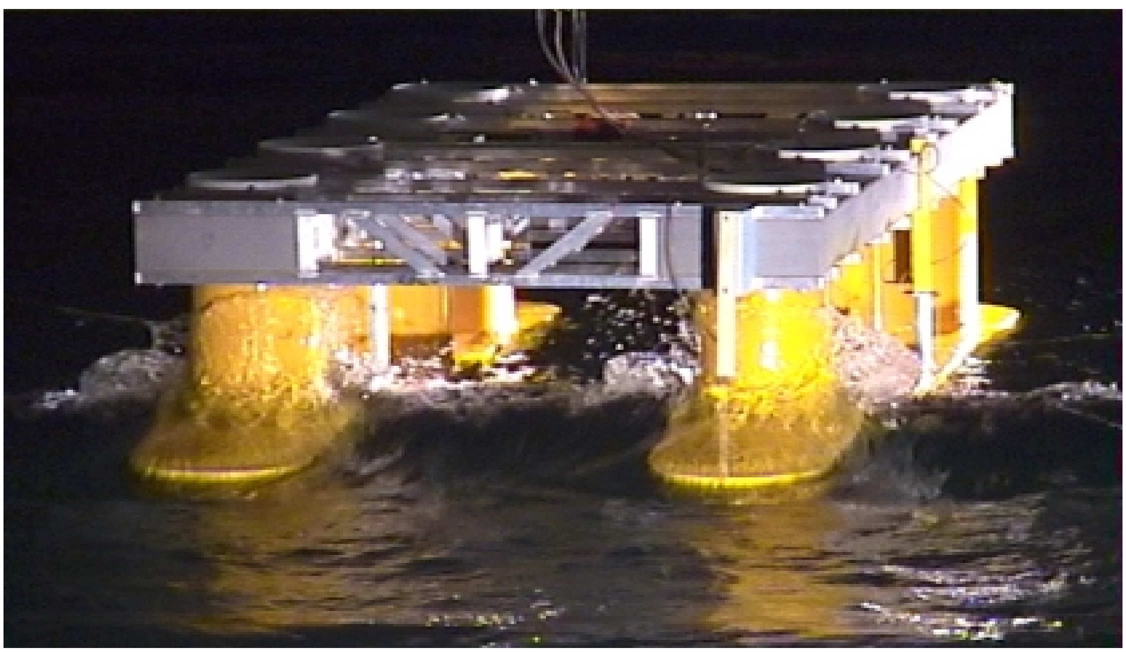

Figure 3. Dynamics in head seas of MOB platform at transit draft (see Kriebel and Wallendorf, 1999).

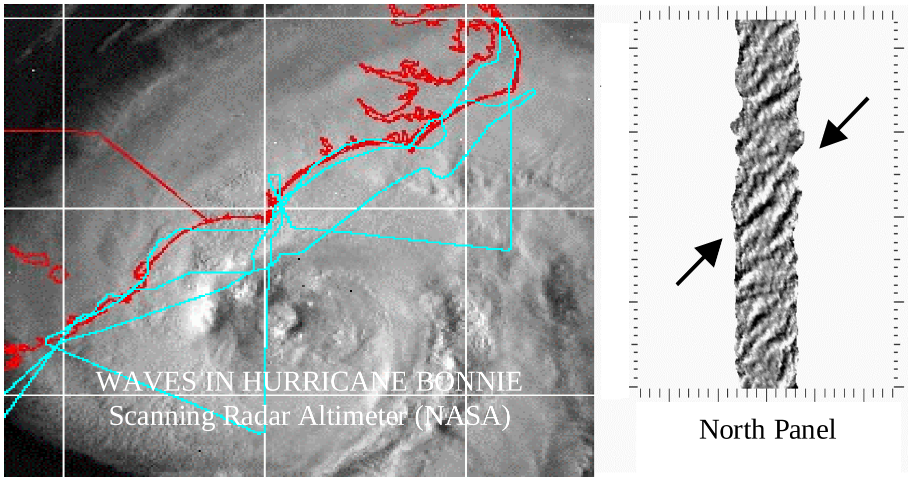

Figure 4. Wave Measurements from Hurricane Bonnie (from Borgman et al., 1999).

largest waves in hurricanes can have straight crests at least 1-kilometer in length (short crests/confused seas were expected based on the continuously-rotating wind direction). The arrows in Figure 4 isolate a large 18-meter high wave with a kilometer long crest identified by the deep (black) trough and the high (white) crest; the panel size is roughly 1 by 6 kilometers.

The second survivability category addresses explosive threats. While the Navy has extensive experience with the behavior and design of displacement monohulls to such events, the response of semisubmersible hull forms has never been evaluated. The results of a preliminary assessment conclude that a MOB is very survivable to explosive threats, due primarily to its large size. This Program sponsored two preliminary engineering studies pending a future study to officially define likely external threats: one that reviewed the range of possible external threats, and one that evaluated the effect of detonation on MOB structural integrity.

Functionality

Recall that the tools associated with the *MOB Classification Guide* address only the structural and stability integrity of a subject MOB module or platform. A similar set of "performance measure" tools is necessary to study and/or predict the effectiveness of MOB platforms in carrying out required mission related operations. The MOB program emphasized objective, probability-based measures of performance and risk. These tools can identify bottlenecks, compare concepts, and quantify the impact of changes in mission requirements and metocean conditions at a site of interest. Three models are described next.

An operational availability (Ao) model (Jha et al., 1999) was developed that statistically estimates the percentage of time the MOB can perform a given mission, such as the maximum rate of aircraft handled or the cargo throughput from a vessel of interest. A key component of this model is the meteorological, oceanographic (metocean) database previously described. The Ao model considers not only the failure rate of key systems and components, but also the percentage of time lost to bad weather at a designated location, as well as other factors that affect mission performance.

A design synthesis model with life cycle costing (Bagnell and Forrestall, 1999) was developed to determine whether a given design provides reasonable geometry, weight, Vol.ume and other parameters for the specified systems and required performance characteristics. This tool checks the completeness of designs and provides cost estimates.

A ship cargo transfer rate model (Cybulsky and Currie, 1999) was developed to evaluate the at-sea transfer rates of container and vehicular cargo between MOB, Sealift ships and lighters. Key factors included cargo handling characteristics and relative motions between the floating bodies.

Constructability

This S&T driver assesses the ability of industry at two distinct scales: building the large semisubmersible modules, and manufacturing all of the associated component hardware.

The first task for assessing constructability was to identify a range of probable dimensions for MOB semisubmersible modules; this was accomplished in the four previously described preliminary system designs. The modules proposed in those studies range from 220m to 500m, and are all longer than the 200m length of the longest existing semisubmersible. Equally important is the fact that the nominal 120m to 170m beam of these proposed modules is much larger than the capacities of existing shipyards. Using this information, an assessment study was conducted which concluded that U.S. industry has the capacity to competitively deliver a full (2 kilometer) MOB (Bender et al., 1999). A risk-based constructability model was developed and used as part of that study.

A variety of studies have addressed the issue of designing and building key MOB subsystems. The emphasis was on connectors, dampers, and a multi-module dynamic positioning (MMDP) system, with some preliminary work on MOB-vessel cargo transfer schemes. For example, a nominal MMDP system was designed scaled from existing practice (and concluded to offer "acceptable" performance), and a separate comparative study of candidate controller logic is underway. All of these subsystem studies concluded that, while further engineering development was essential, no "showstoppers" were identified.

Cost

Estimating the construction cost for a basic MOB (includes hull and basic machinery but excludes military enhancements) is one of the two objectives of this S&T Program. Accurate cost estimates are difficult to project at this time for three reasons: (1) the operational requirements have not been refined, meaning that the platform requirements are unknown (specifically, platform length and beam); (2) the trade-off between acquisition versus life cycle costs have likewise not been decided; and (3) the number of units to be built is not known. Therefore, only approximate information is available regarding cost at this time. Indications are that a single module would cost on the order of $1.5B, with a full MOB platform (2-kilometer length) costing between $5B and $8B.

REMAINING S&T

This S&T program has accomplished a lot in a relatively short period of time thanks to a very talented and dedicated group of participants. But the calendar period has been too short to complete certain efforts that are necessary prior to taking the MOB concept further into an engineering development effort, demonstration, or any similar direction..

A prioritized list of the most significant remaining S&T includes:

- Improve the confidence in the estimates of the global responses by completing the validation of the new hydroelastic models; this is critical to add confidence to the design of vital components such as connectors, and in the process increase confidence in a variety of related estimates such as operational availability for at-sea cargo transfer
- Identify and improve the ability of cargo handling equipment to transfer cargo from MOB to transport craft and quantify the capability of those transport craft for typical MOB stand-off distances from shore
- Potential MOB users must get inVol.ved with the development process to improve the quality of cost estimates, improve the focus of technical development and ultimately develop a more precise performance document.
- Revisit the four system designs using the new, validated analysis tools (item #2 above) and the MOB Classification Guide; the resulting consistency of the designs will aid greatly in the relative evaluation of the merits of each approach
- Verify reliability and performance of key MOB components and systems such as dynamic positioning, connectors and cargo systems through larger scale laboratory or preferably field testing,.
- Continue assessment of ocean wave crest lengths, which are vital to the continued advancement of the MOB Classification Guide

MOB FEASIBILITY

As noted in the independent assessment report (Cheung and Slaughter, 1999) deciding when a concept is feasible is a subjective judgement. Certainly feasibility has limits and this can only be defined once prospective users identify the real requirements for a MOB. However, we can offer the following to support an opinion that MOB is feasible, provided that future hydrodynamic analysis confirms satisfactory global response. The bottom line is that the key issues identified at the inception of the ONR S&T program that put MOB beyond the state of practice, either have been resolved satisfactorily or will be resolved with completion of the few remaining S&T efforts. Potential MOB mission requirements have been deconstructed into design criteria supplemented with specific studies to define parameters such as airfield and cargo requirements, speed, size, and general configuration. A MOB environmental specification was developed and a fundamental design procedure was developed to ensure structural reliability, Hydrodynamic analysis tools have been developed or improved and applied to MOB concepts, although they need to be validated against scale-model tests. Viable construction procedures have been advanced and are determined to be within the capabilities of the shipbuilding industry.

CONCLUSION

At the inception of this ONR MOB S&T program, it was concluded that designing any length serially connected MOB platform was unprecedented and not within the offshore state-of-practice. This Program then embarked on a three year coordinated advancement of the offshore capabilities as they relate to MOB.

The MOB program has brought the offshore industry and academia into new territory, and has been credited with moving many technologies into "the next generation" for general offshore use. This program was managed with an open architecture, including semi-annual meetings to present research results and share information. The specifics of many accomplishments have been published in the technical literature (Remmers et al., 1999), climaxed by several dozen papers at the Very Large Floating Structures Conference held in September 1999. In addition, over 350 technical documents generated by the MOB program are freely available at the MOB Internet site, http://mob.nfesc.navy.mil.

Based on results to date, it is concluded that the use of Mobile Offshore Bases, ranging from one 300-meter long module to a 2-kilometer long platform consisting of serially-aligned multiple semisubmersibles, in the open ocean as a forward base appears technically feasible.

ACKNOWLEDGEMENTS

The MOB program team consists of 16 academic, 15 government, and 25 industry agencies. They have all done an exemplary job of advancing technology in a cooperative manner. In particular we would like to recognize the ONR Program Manager Mr. Gene Remmers. He provided the leadership and guidance throughout this short program that caused us to question everything, to ensure the open exchange of information, and to guarantee that the technology advancements achieved would benefit not only MOB but also the marine community in general. Much of the information presented here was taken from the *MOB S&T Program: An Independent Review* (December 1999), which was written by Dr. Maxwell Cheung and Steve Slaughter of MCA Engineers, Newport Beach, CA with input from independent experts and the entire MOB program team.

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